Photon Pairs from Cavity-Enhanced Parametric Down-Conversion with Tunable Bandwidth for Quantum Interfaces

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Quantum Interfaces

- Physics behind quantum communication and quantum computation is independent of physical system
- Many different systems which excel at specific tasks:
  - Qubits (e.g. single atoms/ions, quantum dots)
  - Sources of entanglement (e.g. parametric down-conversion)
  - Long coherence times (e.g. superconducting circuits)
  - ...
- Long-term goal: interchangeability of components
- *Hybrid* systems

$\Rightarrow$ Interfaces between dissimilar physical systems needed

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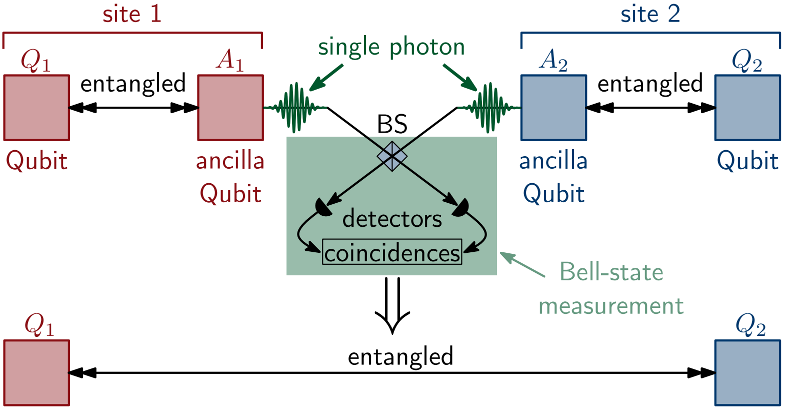
Example: Quantum Repeater

- Fibre optic quantum communication with single photons is limited by losses to $\sim 50 - 100\,\mathrm{km}$
- Concept of a *quantum repeater* to overcome limitation
- Consecutive entanglement swapping: first and last node of a communication channel are entangled
- Quantum teleportation enables communication over large distances
- Communication efficiency scales polynomially with channel length

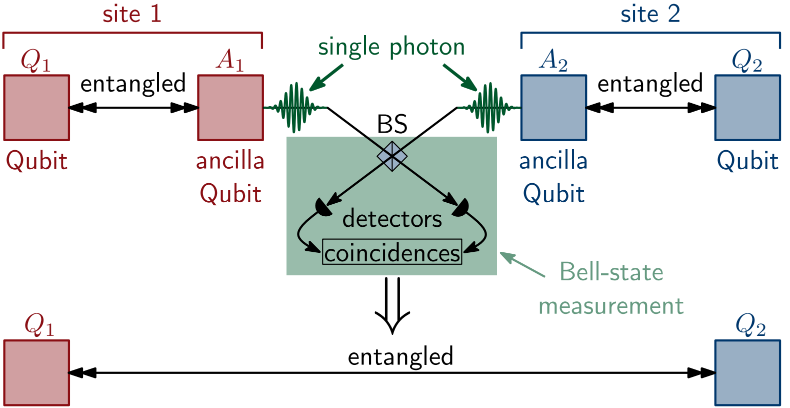
Briegel et al., *Phys. Rev. Lett.* **81**, 5932–5935 (1998)

Duan et al., *Nature* **414**, 413-418 (2001)

Entanglement Swapping



Entanglement Swapping

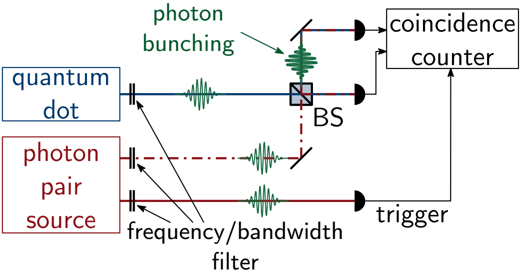


Key components:

- Source of entangled photons
- Indistinguishable single photons from dissimilar sources
- Quantum memories

Quantum Interface

Hong-Ou-Mandel-type experiment:

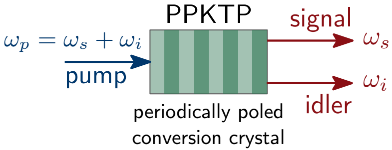


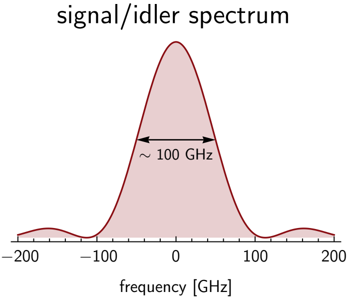
Required quantum dot properties:

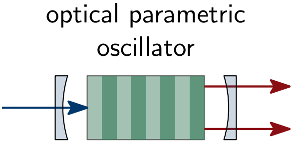
- Bright emission
- Tunable wavelength
- Narrow line width (near Fourier-limited)

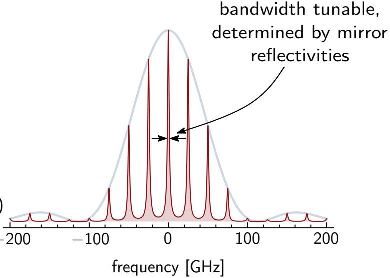
Solomon et al., *J. Opt. Soc. Am. B*, **29**, 319 (2012)

Cavity Enhanced Parametric Down-Conversion









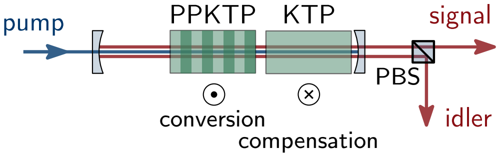
Kuklewicz et al., *Phys. Rev. Lett.*, 97, 223601 (2006)

Wolfgramm et al., *Opt. Exp*, 16, 18145 (2008)

Haase et al. *Opt. Lett.*, 34, 55 (2009)

Triple Resonant OPO with Compensation Crystal

- Type-II parametric down-conversion
- Compensation of path length difference $\Rightarrow$ triple resonance
- Bright emission



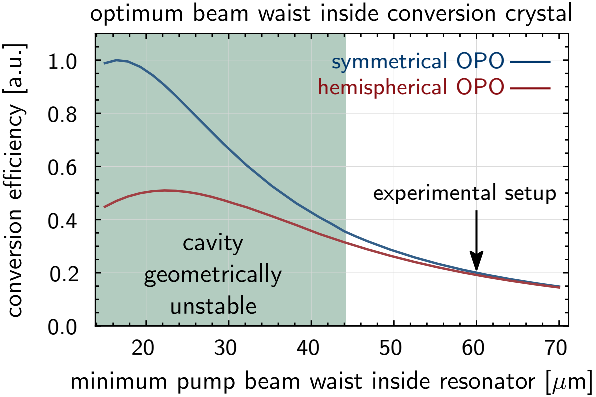
Old setup:

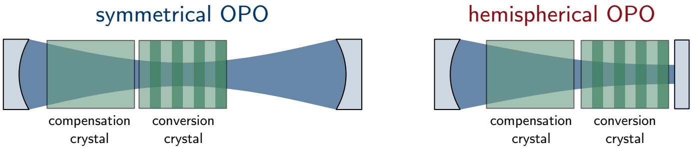
- $\sim$ 3 MHz bandwidth
- 14000 pairs / s / mW / MHz
- Not suitable for experiments with quantum dots

New OPO:

- Compromise between resonator finess and bandwidth
- Design goal: OPO with 100 MHz bandwidth

Geometry: Boyd-Kleinman Theory



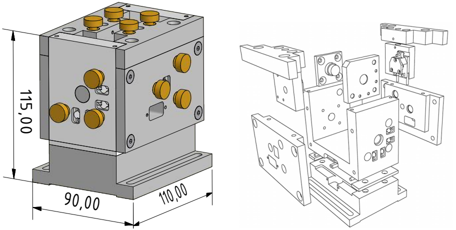


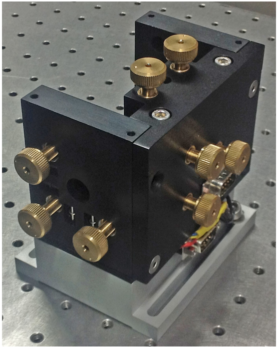
Boyd and Kleinman, *J. Appl. Phys.* **39**, 3597 (1968)

Monolithic Setup

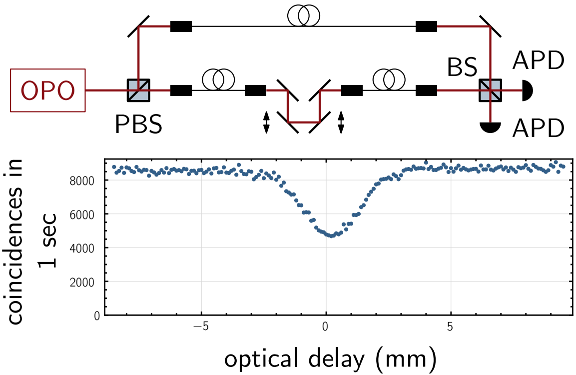
Design Parameters:

- 2 cm long conversion crystal
- Degenerate emission at 895 nm (Cesium D1-Line)
- $\sim$ 100 MHz bandwidth
- $\sim$ 1.9 GHz FSR
- $\sim$ 50 longitudinal modes
- Finesse $\mathcal{F} \sim 20$
- Compact and stable housing





Benchmark: Hong-Ou-Mandel-Effect



- Dip depth currently limited by interferometer visibility
- Repeated dips after one cavity round-trip

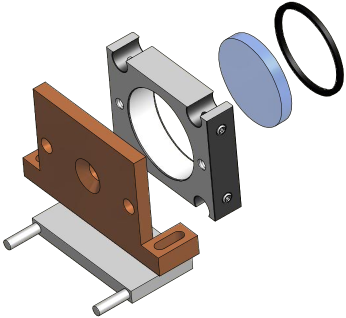
Hong et al., *Phys. Rev. Lett.* **59**, 2044–2046 (1987)

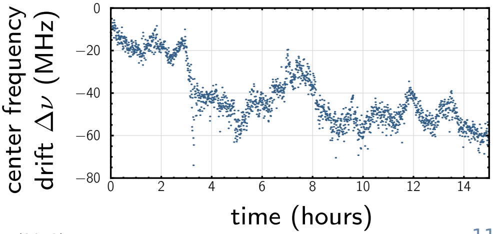
Wolfgramm et al., *Opt. Exp.* **16**, 18145 (2008)

Spectral Filtering

Monolithic Fabry Pérot

- 100 – 700 MHz bandwidth
- 25 – 50 GHz FSR
- $>$85% transmission
- No fast locking required
- Long-term stable
- Spatial filter
- No birefringence with proper mounting
- Low cost





Palittapongarnpim et al., *Rev. Sci. Instrum.* **83**, 066101 (2012)

Outlook

- Filtering of OPO and quantum dot photons
- Show indistinguishability between OPO photons and quantum dot photons
- Incorporate quantum dot spin
- Entanglement swapping experiments

Funding

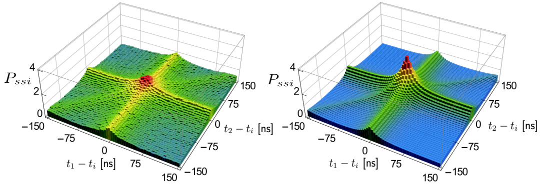
Bundesministerium
für Bildung
und Forschung

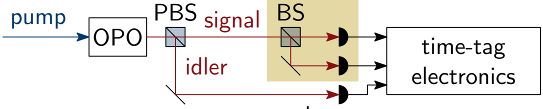
QuaHLRep - project

Time-Resolved Measurements

- conditioned Hanbury-Brown-Twiss setup allows for measurement of time-resolved triple coincidences $P_{ssi}(t_1, t_2, t_i)$

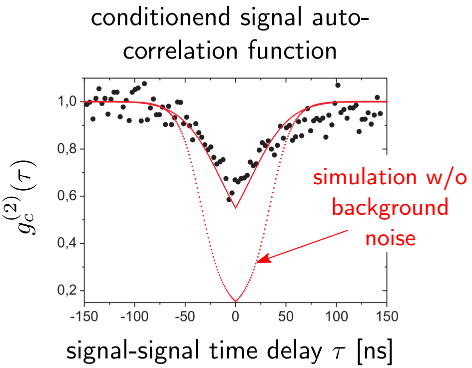
experimental results | simulation

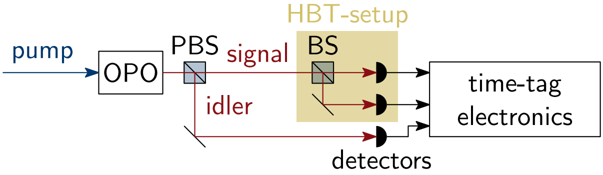




Höckel et al., *Phys. Rev. A*, **85**, 013802 (2011)

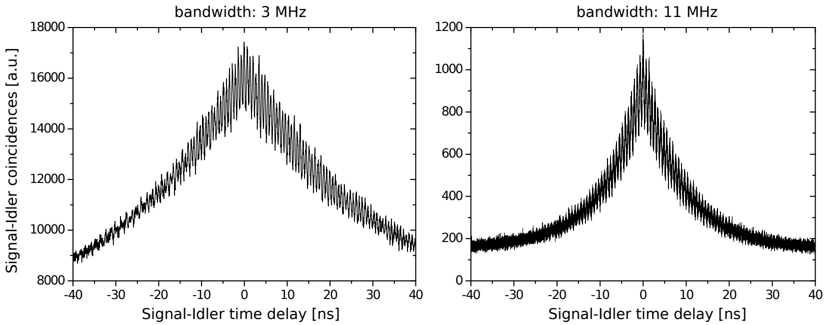
Photon Statistics

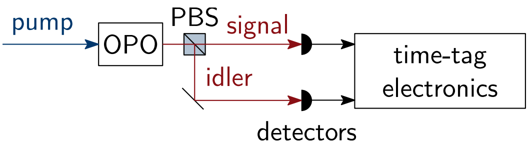




Höckel et al., *Phys. Rev. A*, **85**, 013802 (2011)

Tunable Bandwidth and Temporal Characteristics





Scholz et al., *Phys. Rev. Lett.*, **102**, 063603 (2009)